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THE TEACHING OF PHYSICS

WITH ESPECIAL REFERENCE TO THE TEACHING OF PHYSICS
TO STUDENTS IN AGRICULTURE

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EDUCATIONAL COMMITTEE REPORT NUMBER 4

The Teaching of Physics

With Especial Reference to the
Teaching of Physics to Students in
Agriculture.

A REPORT

by the

EDUCATIONAL COMMITTEE

of the

American Physical Society

Educational committee.

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This report has been prepared by a subcommittee consisting of Alpheus W. Smith (State University of Ohio), W. F. Steve (University of Wisconsin), and O. M. Stewart (University of Missouri). It is hoped that this report will not only be helpful to those who teach agricultural students but also to those who have similar problems. It is also hoped that it will be of service to teachers of agriculture as well as to teachers of physics in promoting a better understanding of the place of physics in an agricultural curriculum and in assisting in making the teaching more efficient.

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THE TEACHING OF PHYSICS

I. Introduction

1. A study of the problems connected with the teaching of physics to agricultural students was undertaken because it was thought by some that the teaching of physics to agricultural students had been less successful than the teaching of other groups of students. It was also thought that physics had not received the recognition the administrators of agricultural colleges that it deserved. It was, therefore, the hope of the committee when it began this work to be able to offer some suggestions to those who are teaching physics to agricultural students and also to those members of agricultural faculties who are interested in the character of the courses required of agricultural students.

II. Summary of Conditions

2. Letters of inquiry were sent to the deans and the departments of physics in practically all the agricultural colleges of the United States. Some of the information obtained will be given in this Section but much of it will be reserved for more appropriate places.

Definite data on the required work in physics was obtained from thirty-three agricultural colleges. Physics is required of all students in fifteen colleges, it is required in seven others of all students who have not had high-school physics. There is no general requirement in eleven colleges. However, in one of these there is a required course in farm mechanics which is largely physics. In a few institutions where physics is not generally required it is required of certain groups of students, for example those who intend to specialize in soils. Some deans report that physics is not required because the departments of physics would not give shorter and simpler courses than those given to engineering students.

There is a wide variation in the amount of time allotted to physics in those institutions which require physics of all students. The specific requirement and the number of colleges are as follows:

4 hours per week for 2 semesters, 1 college.
3 hours per week for 2 semesters, 3 colleges.
5 hours per week for 2 quarters, 1 college.
4 hours per week for 2 quarters, 1 college.
3 hours per week for 2 quarters, 1 college.
5 hours per week for 1 semester, 1 college.
4 hours per week for 1 semester, 2 colleges.
3 hours per week for 1 semester, 2 colleges.
5 hours per week for 1 quarter, 2 colleges.
3 hours per week for 1 quarter, 1 college.

The average requirement is 4.6 semester-hours.

In about one fourth of those colleges which require physics of all students the course in physics does not include laboratory work although practically all deans

state that laboratory work should be given. In the case of those giving laboratory work the average ratio of the number of lecture and recitation periods to laboratory periods is about two to one.

The number of students in a quiz section is usually less than 25, in three cases it is 30, and in two others 40 or more. In the majority of cases the course is given in the sophomore year.

3. Notwithstanding the fact that the time allotted to physics is surprisingly small, the deans do not display much enthusiasm about increasing the time. Apparently some deans think that the student should be trained in agriculture with a smattering of science. On the other hand some of the deans appreciate most thoroughly the necessity of agricultural students having a good foundation in physics. One dean points out forcibly the fact that many agricultural educators have failed to realize how important physics is in the field of agriculture.

In view of the short time given to the course in physics it is interesting to note that most deans agree that it is not necessary to cover the entire field of physics, the most important branches being mechanics, heat, magnetism and electricity. Most of the teachers who do not attempt to cover the entire field agree that these divisions are the most important.

Many teachers state that the course given to agricultural students is not satisfactory. This is due to two causes, lack of time and lack of sufficient preparation of the student. The student is frequently very weak in his mathematical training, sometimes not being able to handle the simplest arithmetical and algebraic processes. The letters from physics teachers describing their attempts to give physics in any but a superficial way are almost pathetic. No one claims to have found a satisfactory solution. Some cover the subject of mechanics rather carefully and the rest rather hurridly. No two departments have exactly the same practice.

4. It is the opinion of the deans that agricultural students should not take the same course in physics as that taken by engineering students. About half of the deans think that a separation of beginning students of physics into two groups, engineering and non-engineering students is sufficient, provided the character of the instruction is adapted to that division, but some wish the division carried much further. A majority of the physics teachers do not believe that the needs of agricultural students justifies a special course. But in some cases special courses are given because no other group of students takes so short a course. One simple means of avoiding a special short course is to have the agricultural students take the first part of a course which runs through the year and which is taken by other groups of students.

Complaints by the deans of a lack of cooperation between the departments of physics and the agricultural administrations are surprisingly few. In only two colleges is a course in physics taught by teachers who are not members of the department of physics.

5. There are three serious aspects of the teaching of physics to students of agriculture:

1. In a considerable number of colleges of agriculture the students take no physics at all.

2. In those colleges which require physics of their students the allotted time is usually entirely too small.

3. Due to the lack of time and of proper preparation of the student the pedagogical problems in the teaching of physics to agricultural students are more difficult than in the teaching of physics to any other group.

III. The Place of Physics in an Agricultural Curriculum

6. The planning of a satisfactory curriculum in agriculture meets with serious difficulties. It is very necessary to lay an unusually broad foundation. The student needs a thorough training in the biological sciences, with courses in both botany and zoology. In addition he must be trained in physical science with courses in both chemistry and physics. No other professional student, except perhaps one in medicine, needs such a variety of courses in science. In medicine, which is at the least a six-year course, no curriculum has been constructed which is satisfactory to every one. But in agriculture, where the work must all be crowded into a four-year course, the situation is far more difficult. The faculty committee which plans the curriculum finds that practically each department in the college, and there are often a large number of them, wants one or more of its courses required of all students. The usual result is that the foundation courses are shortened until the student often gets only a smattering of the things he should learn well. In many cases much needed work is omitted entirely. It is no wonder that the curriculi in agriculture have received so much severe criticism at the hands of the men in the general sciences.

In many professional schools there is too much of a tendency to give factual courses, and often too many of them, rather than to confine the requirements to those that teach fundamental principles. The technic of today will not be the technic of tomorrow, but the fundamental scientific principles of today will be those of tomorrow. The course in agriculture should not be a smattering of the fundamental sciences with a lot of agriculture thrown in. It should be a thorough training in the fundamental sciences with enough agriculture added to teach the student how to apply scientific methods to the various agricultural problems. Only with this type of a course will the student be well prepared to study agricultural problems the rest of his life.

It is extremely difficult for one who believes in a student getting a firm scientific foundation to understand how any faculty of agriculture can justify the omission of a course in physics from its requirements. It is now generally recognized that most of the sciences are using to a greater and greater extent the methods and concepts taught in physics. Today in the biological sciences many of the methods and principles of physics are used. More than ever before do their students need to understand physics. The methods used in agriculture are changing. It is becoming a quantitative science using the methods and principles of chemistry and physics. Already in many courses, for example, soils, a knowledge of physics is necessary. There is no doubt that physics is today furnishing much of the foundation material to the science of agriculture. A few years ago, the teachers of agriculture in one institution reported to an investigating committee a long list of topics of physics which they thought should be understood by their students. (This list

is given in Section 18.) It is becoming more and more obvious each year that agricultural students need a thorough training in physics.

At a time perhaps when the importance of the teaching of physics to agricultural students was not as well appreciated as at present, a number of agricultural colleges added physics to their curriculi. In nearly every case the time allotted was small, entirely too small. Even now the average requirement is a little less than five hours per week for one semester. The subject of physics consists of five related branches, each branch having many fundamental principles which are related to agricultural problems. It takes time to cover the field in a way which will give the students the drill and understanding of the more essential principles. It is no wonder that there are frequent complaints that the course in physics is superficial and that the students do not learn how to apply the principles of physics. It will be pointed out in Sections 11, 12, and 15 that the best method of learning the principles of physics is to learn many applications of them. It is only by systematic drilling in the applications of the principles that the student acquires facility in their use. And this requires time. The kind of teaching that is needed (see Section 13) cannot be given in short lecture courses.

In planning a curriculum there is an important matter that is sometimes overlooked. More attention should be paid in the first two years to the subject matter which the student will not have given him again in later courses. For example, if the student will have a great deal of applied botany in later courses, does he need in the early part of his course more than a short elementary course in botany? On the other hand, if the course in physics is the only one in which he will be drilled in the fundamental laws of force, energy, heat, electricity, etc. should not that course be given greater emphasis? The course in physics is the only course where agricultural students receive training in these fundamental principles. On the other hand students now receive in different courses over and over again the same biological principles. In the colleges of engineering the students are taught physics in most of the advanced technical courses. The precise number of hours of physics explicity required in engineering curriculi does not represent the amount of physics that the student needs or is taught. A teacher of an agricultural subject must not assume that if ten hours of physics is required of students in engineering ten hours is more than the amount of physics needed in an agricultural curriculum. For the simple reason that the course in physics in the agricultural curriculum is the only place where the principles of physics are taught, the course should receive greater emphasis. One prominent chemist, who is closely in touch with the work of agricultural colleges, states that students in agriculture should be required to take at least as much work in physics as is now required in engineering curriculi.

There is a general agreement among teachers of physics that the time allotted to agricultural students is too short, that the work is superficial and unsatisfactory. Apparently many of them feel that the case is almost hopeless. From the standpoint of these teachers the only solution is to lengthen the requirement.

7. Summary of reasons for greater emphasis on the course in physics.

1. The importance of giving greater stress to the student acquiring a thorough foundation as a preparation for scientific work.

2. Methods and principles of physics are being used more and more in agriculture as well as in all biological sciences. The list of topics in physics that students need in their courses is a long one.

3. The course in physics is the only place in the curriculum where the fundamental principles of force, energy, heat, electricity, etc., are taught.

4. A course in physics covers five different branches, mechanics, heat, magnetism and electricity, sound, and light. Several of these are important enough to be given the entire time of the present course.

5. Physics is a hard subject, largely because the student is rushed too rapidly through the work. Not enough time is given for the students to digest the material.

6. It is most important that the student should learn his physics in such a way that it becomes an effective tool. This requires much time in drilling the student on the applications of principles. In most cases the subject is given in such a hurried manner that it is not of great use to most students.

7. Most of the graduates of agricultural colleges become teachers, research men, extension specialists, county agents, or other kinds of agricultural experts. This fact makes the need for a thorough training in fundamental science more important than if the graduates went back to the farm.

IV. The Need of a College Course in Mathematics in an Agricultural Curriculum

8. Many of the students who enter the agricultural colleges are poorly prepared in mathematics. This is partly due to the system of accrediting high schools which has become so widespread. Under this system a state institution must accept a graduate of an accredited high school no matter, within rather wide limits, what subjects were taken in the high school. In many instances it is impossible or very difficult for a college of agriculture to require that the student must take a certain amount of mathematics in the high school. In fact a few students are now entering these colleges without having had plane geometry. Then too many of those who have had high-school mathematics have for one reason or another forgotten most of it. Teachers of chemistry and physics complain that a considerable proportion of the students cannot solve the simplest sort of an algebraic problem without help. But the physics and the chemistry teachers are not the only ones who complain. There are a number of courses in agriculture where the student needs some mathematical skill. In many cases statistical methods are used and teachers find that some of the students cannot solve problems involving percentages. It should be unnecessary to point out here the need for simple mathematics in the various occupations that the graduates of agricultural colleges pursue. Most of them need to be able to make many different types of computations.

Agriculture is becoming more and more a quantitative science. Algebraic formulas are now found in published bulletins and in magazine articles. In some types of work where the methods of physical chemistry are followed calculus is used. It is a serious question whether the student of today who takes no college mathematics will not in a few years find his lack of mathematical training a serious handicap.

Of the fifteen agricultural colleges which require college physics of all students ten require a college course in mathematics. But of those colleges in which college physics is not required or is required of only part of the students the majority do not require college mathematics. The result is that in many of our agricultural colleges the teacher of physics finds it very difficult to teach physics. Much of the serious troubles in the teaching of physics to agricultural students can be traced to the lack of a mathematical training in very elementary mathematics. Teachers of physics and teachers of agriculture should unite in getting this situation remedied. We believe that all colleges of agriculture should require a freshman course in mathematics, except in those cases where they can be assured of a good high-school course in mathematics being given to all their students.

No investigation has been made of the type of courses in mathematics given in the agricultural colleges. However, it was found in several cases that the required course was specially designed to give the student a review of high-school mathematics and some of the more important things that are usually taught in the freshman courses in algebra and trigonometry. It is important that the use of mathematics as a tool be emphasized.

V. Some Suggestions on Methods of Teaching Physics

9. The teaching of agricultural students presents many important difficulties. Some of these are common to all courses in physics, but there are others which are special. Agricultural students are usually not interested in physics. A dean of one of the more important colleges of agriculture stated that agricultural students were less interested in physics than in any other science. Engineering students are as a rule much more interested. They usually realize that a knowledge of physics is necessary in their technical work. Then too their preparation is better. Hence a teacher of physics does not need to pay so much attention to devices for making his work successful when teaching engineering students. But in the case of the teaching of agricultural students the teacher should use every method which will help him.

So much of little value has been written on the psychology of teaching and so extravagent have been the claims made for the theory of teaching that many college teachers are prejudiced against everything that is written on the subject. There really has not been much written on the sepcific problem of the college teacher of physics. Good teaching is largely a matter of common sense and industry and the utilization of those practices which have resulted from the observation of successful teachers of physics. There is therefore not much that should be called to the attention of the physics teacher in this report. Indeed if he has not learned from his years of observation as a student and as a teacher a great deal about teaching then it is hopeless to attempt in a few pages to give him the fundamental principles of good teaching. However, it is thought advisable to state here a few points which are usually not given the attention which they deserve.

10. *The teacher should have in mind the aims of the course and the aims of the student.* It is very important that a teacher should have definitely in mind the aims or purposes of any course which he gives. If he does not have these clearly in mind he

may fail in achieving one or more of the important purposes, or he may waste time by using material or methods which have no bearing on the purpose of the course. In addition to having definite aims himself the teacher should know what is the probable aim of the student. For good teaching usually means that the teacher begins his work with the aim of the student in mind and gradually leads the student to have other and often higher aims. It is very important that the aims of teachers and those of the student should be as nearly identical as possible Let us first consider what are those aims of an elementary course in physics which are quite generally accepted by teachers of physics.

One can find many different statements of the aims of an underclassman course in physics. Most of these can be put in one of the following groups:

1. Training in the scientific method of thinking, especially in quantitative methods.

2. Imparting a knowledge of those laws, facts, and experimental methods that will be useful to the student.

3. Training in special fields, such as observation, imagination, initiative, and ingenuity. (One of the relatively recent conclusions of psychologists is that such training is not general. A training in observation in physics does not necessarily train one to be a good observer in other fields. These qualities are far more specific than we formerly thought they were. Hence this group of aims is not given today the same relative importance as formerly).

There are others but these are sufficient for the purpose of this report. It is not worth while to try to state which of these is the most important. In general, they go together. For example, we can not teach the first to the student without also teaching the second.

The aims of the student are frequently quite different from those of the teacher. In the colleges of engineering physics is usually accepted as a very important element. The teachers in the advanced courses continually use facts and principles of physics. This is so well known that in many engineering colleges there is a tradition among the students that it pays to understand physics. In such schools the aim of the student is usually the second one, that he wants useful information. It is much more difficult to state definitely what the aim of the agricultural student is. Too often he takes physics because he must have it to get a degree, it is a necessary evil to be disposed of as best he can. Such a student should be supplied as quickly as possible with a worthy aim. The easiest one to give him is that it is worth while to study physics because the information is of much value. This can be done by using illustrations drawn from things witb which he is familiar, and about which he knows that he needs more information.

Too many teachers do not appreciate the above point. Too often they assume that students have the same motives and the same interests that they had when they were students. It is hard to realize that there is such a great divergence of aims and interests. The formulas and methods that appeal to a specialist often have no meaning whatever to the average student. Teachers should realize fully the importance of teaching beginning students by methods entirely different from those used with advanced students. To choose examples that will illustrate the principles of physics and yet deal with facts with which the student is familiar

requires careful planning on the part of the teacher. The significance of the principles of physics as applied to the daily life and thoughts of the student must be made clear. When this is done not only are the principles clearer to the student but he has been supplied with a worthy aim or motive. This is nothing more or less than what is sometimes called "selling the subject".

There are teachers who say that we are lowering our standards in adopting such methods, that we should hold our students up to higher ideals. This attitude is often taken by teachers because they do not understand clearly just what it is that is advocated. It is not desired to cheapen the course by introducing spectacular experiments, or by using illustrations that are merely interesting. The purpose is to teach fundamental principles of physics by means of illustrations drawn from things with which the student is familiar and in which he is interested. It is not, when correctly done, a lowering of standards, for the principles can be taught with even more thoroughness when we begin with familiar facts and methods than when we begin with more abstract things. In fact this method encourages less superficiality on the part of the student than the other methods. No one need worry about making physics too easy for it is a hard subject to many students, in fact it is often too hard. In many instances, the average student digests very little of the subject. It is a mistake for teachers to overlook the importance of supplying a motive to the student. It is almost a necessity that it be done. For if it is not the teacher's success is made much more difficult.

The aims of the faculty which requires the student to take physics should also receive consideration. Some of the agricultural teachers would stress the first of the aims given above. But probably most of them would state that the second aim was more important. Many of them would probably argue that the physics teacher should give facts and laws which would be useful to the student for, in so doing, the work not only makes a more immediate appeal to the student but these facts and laws are as well suited as any others for training the student in scientific thinking and in accomplishing the other ends which the teacher may have in view.

It should be clear, without going into further details, that the teacher of physics should pay a great deal of attention, especially in the first part of the course, to teaching facts and laws that are useful to his students. Teachers and textbooks of physics are prone to use illustrations drawn from engineering fields. These illustrations often mean very little to a student who is not familiar with mechanical devices. It is very important that each teacher should collect for use in the class room a fund of illustrations drawn from daily life, things of household interest, things seen on the street, the weather, and in general those things about which the student already knows something. Applications to simple agricultural phenomena should be used freely. In this way the teacher can soon build in the mind of the student a definite interest and aim in the course. While the teacher is doing this he can also develop the other aims which he thinks are important.

Each teacher must be certain that he understands the attitude of the student. Then he must give the course in such a way as to give the student a definite aim and interest. Then and then only can he succeed in accomplishing what he regards as the chief purposes of the course.

11. *Generalizations must be made only after a large number of specific cases are understood.* In the usual method of acquiring knowledge one learns first a large number of facts. Later he may be able to generalize and to employ more or less abstract methods of reasoning. He does not begin by learning generalizations. To realize that this is true one has only to recall his own training. Generalized thinking is so common with physicists that often they do not realize how vague it may all be to students. Too often the student of physics is introduced to the subject by being confronted with definitions or general statements that he cannot understand. Generalizations should not be made until the student has first learned a number of specific cases. For example, in understanding even so simple a law as the Newtonian law of gravitation, attention should be first called to the fact that the earth attracts bodies on its surface, that it attracts the moon, and then the student should learn something of the experiments showing the attraction between other bodies. He can then understand the generalization as stated in Newton's law. One teacher year after year asked a student who had just "recited" Newton's law what the law meant. The usual answer was that it meant that the earth attracted the moon (this probably was the illustration used in the textbook.) He then asked the student, "Does this piece of crayon attract this other piece?" A common answer was "No". Yet that student had just stated that "every particle in the universe attracted every other particle....." Nearly every teacher has observed a similar inability of students to apply generalizations. The teacher must clearly appreciate the fact that a general statement means nothing unless it calls to one's mind a large number of specific cases.

In selecting the specific cases that should be taught the teacher should select those with which the student is familiar and those in which he is interested. In doing this the particular interests of the student must be kept in mind. The teacher must be certain that the cases selected as illustrations must be concrete to the student. Much of our demonstration apparatus is not concrete to the student. He never saw or heard of it before. He does not understand it. How can the machine illustrate a principle when he does not understand the machine? The mere seeing of a piece of apparatus on the lecture table does not always make the apparatus concrete. Many teachers have marveled at the inability of students to recall accurately the result and the purpose of a particular demonstration.

In teaching a general principle the teacher should begin with the concrete and should give the student clear ideas of the entire field before the generalization is given.

12. *Students learn to apply generalizations only by learning a number of specific applications.* It is a very common mistake to assume that the student can learn for himself how to make the applications of a general principle. The inability of students to make applications of general principles to new problems is the basis for much of the criticism by other departments of the teaching of physics. There seems to be only one way to train students to make applications of a principle over a wide field and that is by pointing out to the student many applications and in encouraging him to find others. These applications should be so chosen that they cover a variety of special cases. Then when a new problem comes to the attention

of the student he is more likely to find in the new problem some element common to another case which he understands and thus will be able to find the correct principle to use. A student might not apply the principles of adiabatic heating or cooling of gases to atmospheric currents unless he knew some related application. There is no doubt that the ability of a student to apply his knowledge of physics is one of the most valuable things he can derive from the course. The value of the course in physics in an agricultural curriculum depends very largely on whether the physics is taught in such a way that the students do learn to use it.

As the student learns to apply the principles his interest in the subject increases and he puts greater effort into his work. In fact there is no better way of stimulating real endeavor. It is also obvious that under these circumstances it becomes relatively easy to train students in scientific methods of thinking.

In choosing matter to illustrate principles teachers will have to use material not given in the textbook. There is no textbook that contains enough illustrations or has space for enough of them. The teacher must supply these in the class or lecture room. In Section 21 are given some agricultural applications of principles of physics. It is hoped that this list may serve many teachers as a nucleus to which can be added other applications as they are found.

Students learn a generalization by learning specific cases. After they understand the generalization they learn to apply it by learning a number of applications. To be able to understand and to apply a principle the student must begin with the concrete and must end with the concrete.

13. *Physics is best taught in small classes.* It is a common way of teaching elementary classes in physics to use simultaneously three different methods of presenting the subject: (1) demonstration lectures given to a large group, (2) recitations and quizzes in small groups based on lectures and textbook assignments, and (3) individual laboratory work. The distribution of time between these different methods varies widely. But the reports received from teachers in charge of the course of physics given to agricultural students show that the first method dominates in a number of institutuons. The lecture method with elementary classes is an inheritance from the time when we had no textbooks. The continuation of its use is by no means a proof of its efficiency. Certainly it is well worth while for teachers to consider whether the lecture to a large group of students is desirable, expecially when that group consists of students who because of deficient preparation or lack of interest are difficult to teach.

The advantages of giving formal demonstration lectures are obvious and well known. Undoubtedly it saves the time of the teaching staff. On the other hand the pedagogical disadvantages of teaching underclassmen in large groups by the lecture method are very serious. So serious are they that an attempt will be given here to point out some fundamental considerations.

The various methods of teaching may be divided into two classes: (1) the "telling" method, and (2) the "developing" method in which an attempt is made to develop the student's reasoning power and his ability to apply the principles he has learned. In deciding which of these two methods should dominate one must again consider the purpose or aims of the course. By the first method the facts and

principles of a subject can be taught. But this is not all that is desired in a course in physics. The investigation made by a former Committee* showed that a majority of teachers of physics in engineering schools believed that the most important aim of a course in physics should be to train students in scientific habits of thought. It has been pointed out before that it is of great importance that a student learns how to apply the principles of physics to new problems. Independently of how we classify our aims, there are some very important features, perhaps the most important, that cannot be taught by the lecture method. Students learn how to think only by thinking. They learn how to apply principles of physics to new situations only by doing it. They need a great deal of help and guidance in learning to apply these principles. They need a method of teaching which can be used only in small classes.

If a student is to receive this type of training that is so valuable, not only must the class be small, preferably about fifteen, but the teacher of that class must use the "developing" method. He must not do most of the talking. He should not merely quiz or ask students to "recite". He should expect the students to discuss things. Where textbook assignments have been made time should not be wasted duplicating what is clear in the textbook.

There are other pedagogical objections to lecturing to large groups of elementary students. The difficulty of securing interest and attention is well known. There is also that very serious difficulty due to the inability of an instructor to determine how efficient his lectures are. Sometimes the teacher is sadly deceived with respect to how well the student has understood the lectures. Teachers who come into intimate contact with students in small classes are frequently surprised at how difficult the subject is to the average student and how superficial the student's knowledge is. It is a very difficult matter for a lecturer to be certain that he is giving the lectures in such a way that the student digests the material and also to be certain that the lecture method does not encourage loose thinking.

But in this report it is desired to draw particular attention only to one objection. That is that the lecture method gives too much emphasis on one type of instruction, a type which does not give training in what many regard as the most important aim of the study of physics. (It should be obvious that we have in mind an elementary student of a rather special type. Mature students and possibly engineering students will do the necessary thinking, solving problems, and the like, outside of the lecture.)

In several institutions other than lecture methods have been tried. In some cases two methods have for the purpose of comparison been used simultaneously. In all cases, so far as is known by the Committee, teachers who have tried teaching small groups with no large group lectures believe that the small group method is decidedly superior. The method used in one institution will be described in some detail. The class meets in sections, with not more than twenty-five students in each section. All of the sections meet in the same room. For example, one section may meet Monday, Wednesday, and Friday at eight o'clock, another at nine o'clock on the same days, another at ten, and so on. These class meetings are a sort of combination of lecture demonstration and recitation. Experiments are performed in a very

* P 28 The Teaching of Physics. Report Number 1 of the Educational Committee of the American Physical Society.

informal way, both the class and the teacher asking questions. As textbook assignments are made for each meeting, part of the time is spent in discussing the text, in discussing other applications of the principles, and in working problems. Different instructors may be in charge of different sections. However all follow the same textbook assignments, which are made out in advance. At more or less informal meetings the instructors agree on what demonstration experiments shall be shown. The needed apparatus is then set up by an assistant. Experience showed that there were a few difficulties, which could be avoided with a little care. It was found that some instructors did not take the pains to become so familiar with the apparatus that they never had failures of their experiments. (It is very necessary that demonstration experiments should work. No failures should be tolerated.) There was also a tendency for extra apparatus to be set out on the table because one of the instructors wanted to show something a little different. But usually both of these difficulties are easily remedied.

When a large number of students is taught, the use of only small classes requires more time of the teaching staff than if the demonstrations had been given to a large group. For example, if the course is given according to the old plan there might be two lectures a week to all, one quiz each week to small groups, and two laboratories per week. If there had been one hundred students, this would have required four quiz sections, or six class meetings per week including the lectures. If there had been no lecture to a large group and the class had been divided into four sections meeting three times a week, there would be twelve class meetings per week. The difference is not small. However in many cases, departments can get more teachers when they can show that the teaching schedule demands it.

The departments of mathematics and of languages have trained the administrative officers to believe that these subjects can be taught only in small sections. The results which have been obtained indicate that it is just as important that so difficult a subject as physics should be taught only in small sections. It should not require a very great effort, if persistently pressed, to convince an administration of this.

In many departments of physics some member of the staff has spent much time in planning a lecture course with demonstration experiments. In a sense it is hard on him to discontinue the large lecture. However, it is a very great advantage to give all the instructors who assist in teaching a course an opportunity of handling demonstration apparatus. Usually there results a feeling of greater responsibility and an increased efficiency. It is true that when the demonstrations are given in the class room rather than in the lecture room there may not be so many experiments shown. But on the other hand, the experiments which are shown are much better understood by the students.

It is not contended that this change in the method of teaching elementary classes will solve all the difficulties. But it is thought that the apparent success of the use of only small classes warrants others trying it.

14. It is very important that every teacher of physics should be certain that the methods of teaching he is using give to the student not only the facts and principles but also train him to apply the methods and principles of physics.

VI. The Character of a Course of Physics for Agricultural Students

15. *Criticisms of present methods.* Criticisms of the present methods of teaching physics were given by a number of the deans in response to a request. These criticisms should not be lightly rejected but should receive the serious attention of all teachers. The principle criticisms which the committee have received are as follows:

1. The course is too theoretical and mathematical. Some of the methods and concepts are too advanced for the average student.

2. Teachers are trying to train physicists. Perhaps unconsciously they tend to prepare students for more advanced work in physics or closely related subjects. In other words, they place emphasis on facts, principles, and methods which may be useful only in advanced work in physics. (This criticism was frequently made.)

3. The course is "dry as dust", due to a lack of sufficient and well-chosen illustrations, or applications, of principles.

4. Lack of sympathy of teacher with the problems in which the student is interested.

5. Teachers are commonly in sympathy with engineering problems and tend to use methods and illustrations suitable for engineers with students who have no engineering bent.

6. Students are not trained to regard their knowledge of physics as a tool. They do not learn to apply principles and laws to new problems.

7. Physics is taught as a pure science instead of an applied science.

The first two of these refer to the choice of methods and to the relative emphasis placed on different principles. The usual explanation regarding the complaint that the course is too mathematical is that it comes from students who have practically no knowledge of elementary algebra and simple geometry. But mathematics is such a powerful tool to the physicist that he probably does tend to use it to the maximum extent. It would not be surprising if he occasionally went too far. When students choose their professional schools there results a classification of students which is based on their inclinations and previous training. Undoubtedly there is a tendency to group into the agricultural colleges students who are not interested in mathematics or in mathematical methods. One who is naturally interested in mathematical methods does not always appreciate how unconvincing these methods may be to others. There probably is too much basis for the criticism that teachers tend to make the course in physics too mathematical.

The second criticism made is that a teacher tends to place emphasis on the facts, principles, and methods in which he as a physicist is interested. Time is so short in the class room that a teacher must choose and unless he does follow a rather carefully prepared plan there is danger of letting his own personal interests dominate. The teacher must continually keep in mind the broad purposes of the course and must also keep in mind the special interests of the students. In most cases the students will get a broader understanding of the methods and principles of physics if the teacher takes full advantage of the interests of the students. This is a matter which involves so intimately the class-room methods of a teacher that each teacher must solve this question for himself.

All the other criticisms refer to the lack of a sufficient use of applications of principles or to an unwise choice of such applications. An attempt was made in

Sections 11 and 12 to point out that good teaching demanded, first, that a teacher or a textbook should start with familiar facts and only after the ground was thoroughly prepared should a generalization, a principle, be stated; second, that after the principle was understood the student should be led to understand many applications of the principle. The use of this method is very important. Teachers must always realize that generalizations are hard to learn and hard to apply. The learning of a general principle should begin with concrete things. In selecting these concrete applications the teacher must utilize problems in which the student is interested. Every teacher should keep in mind that the making of generalizations and their applications are so relatively easy for him that he forgets the untrained condition of the student.

A discussion of the inability of students to make applications of the principles of physics to new problems would involve that difficult and much discussed pedagogical topic of the transfer of training.* Psychologists tell us that a student can transfer training in one situation over to a new one only when there are elements in common. But we are still in the dark as to methods of identifying these elements. The only safe plan is to give a student a large number of different applications of a given principle chosen from different fields. This will increase the diversity and range of his knowledge of the applications of the given principle and his ability to transfer the principle to new problems.

However a teacher cannot train a student to use physics by teaching many applications of the principles unless the teacher is given more time than many of the agricultural colleges now grant to the teaching of physics. The subject of physics contains five rather distinct divisions, each one containing a large number of important principles. At present, in many cases, the teacher is expected to cover the entire field in a time so short that there is no time for any serious drill work. In fact, the student is rushed from one topic to another so rapidly that he becomes confused. If the teaching of physics is to be effective sufficient time must be given. When one realizes how little the student really gets from these high speed courses he wonders whether such a course does not do more harm than good.

There is another reason for the failure of teachers to make their work effective. It sometimes happens that they do not receive the proper kind of support from the teachers of professional subjects. For example, one well-known teacher of an agricultural subject is said to tell his classes when they reach a certain point, "Now I want you to forget all you have learned about chemistry and begin all over again." Such a remark is repeated away from the class room without any explanation of what the teacher has in mind. Under the circumstances it undoubtedly interferes with the teaching of chemistry in that institution. Teachers of professional subjects should make very clear to their students the value of the preliminary courses the student has had.

16. *The segregation of agricultural students.* It is a common practice for departments of physics to divide their beginning classes into two groups: one consisting of engineering students and others who have had a sufficient mathematical pre-

* See Chapter VIII, The Teaching of Physics, by C. R. Mann, The Macmillan Co.; also Chapter VII, Principles of Science Teaching, by G. R. Twiss, The Macmillan Co.

paration to enable them to take a somewhat rigorous course, the other consisting of liberal arts, premedical, and agricultural students. This division into two groups has been forced on teachers on account of the very great difference in preparation of these groups of students. In the report on Physics in Relation to Medicine (Report No. 2) the Educational Committee thought that this was a sufficient subdivision and that the giving of a special course to premedical students was not feasible. The investigation made by this Committee shows that the teachers of physics are generally agreed that a special course for agricultural students is not necessary. About half of the deans of the agricultural colleges are satisfied with the division into two groups. But there are quite a number who think the division should be carried further. However, there is no evidence that those who wish a further subdivision desire it for the purpose of "agriculturizing" the subject. They apparently desire it to collect together in one class students of like interest, in order to make it easier for the teacher to select illustrative matter which all students can understand. The necessity and advantage of using familiar applications of principles has been stressed elsewhere. Undoubtedly the choosing of effective illustrations is a simpler problem if students having different interests are in different classes or sections. But it so happens that many of the applications that one may wish to give to agricultural students are of rather general interest and readily understood by all students. Hence agricultural applications can be used even though the classes contain students from different colleges. However, the grouping of agricultural students into the same course with arts and premedical students should not prohibit the segregation of agricultural students into separate sections. In fact such a segregation has many advantages.

In some institutions special courses in physics are given to agricultural students. This has sometimes been due to the fact that these students cannot spend as much time on the course as other students. However, there are institutions where a serious effort has been made to give a course specially designed for agricultural students. Undoubtedly this would receive the warm support of the deans of agriculture if attempted in other institutions. However, most teachers of physics do not at present approve of this further subdivision of the elementary teaching. Then too there is apparently a tendency of the deans who have direct control of the departments of physics to object to a multiplication of elementary courses in any one subject.

To summarize, there is a general agreement that agricultural students should not be given the same course as engineering students. It is also thought desirable that in those institutions where agricultural students take the same course as that taken by arts and science and premedical students it would be a pedagogical advantage to segregate the agricultural students into separate sections.

17. *Should the course given agricultural students be a general one*? There has been a great deal said about the difference between a *special* and a *general* course in a science. Frequently it is not apparent from these discussions what is meant by the term general. A course might be general in several different ways. Some discussions seem to imply that a course is general or not depending on the type of students in the course, whether the students in the course are specializing in different fields or or are specializing in only one field. In this discussion the term general will be used

as applying to the purposes or the aims of the course. If the purpose of the course is to train students in the scientific method of thinking and to impart a grasp of the fundamental principles which underlie the science then the course is a general course, but if the purpose is to train the student only in the use of those principles which it is thought he needs then the course is a special course.

The subject of physics has grown so rapidly and has spread out into so many new fields that it is not easy to settle the question as to how general a course in physics should be. The subject has become so large that a much greater amount of time is now required to cover the field. Then too some of the principles which have been recently developed, for example, those dealing with *quanta* and *relativity*, are so difficult that the elementary student cannot, without much time and effort, understand them. Hence there are two limitations to our ability to cover all the fundamental principles of the subject, (a) time, and (b) inherent difficulty.

On account of the above limitations most teachers will say that the course should be made as general as time permits. These teachers are thus compelled to make some modifications and some adaptations. When they begin to omit parts they quite naturally begin to think of the needs of the student and omit those parts of which the student is less likely to need a working knowledge. Let us now look at the probable attitude of those who believe in special courses.

A special course is one planned to meet the actual needs of students. But when one comes to investigate what are the actual needs of the student he is impressed with the fact that these needs are continually changing. For example, the science of agriculture is changing rapidly, an agricultural student needs today facts and principles the need of which no one suspected a few years ago. Hence in planning the course the teacher actually extends his course beyond the immediate needs of the student and tries to include what may be needed in the next decade or so. The result of this extension of the so-called special course and the limitation of the so-called general course is that the two classes of courses are not far apart. In fact it may be impossible to distinguish them. An inspection of the outlines of courses shows very little difference.

Hence it really does not make much difference whether we believe that the course must be general or not for we are compelled to pick and to choose between different topics. If we must choose, certainly we should take into account the needs of the student.

In adapting the work to fit the limitations of a four or five-hour course for one semester some teachers try to cover in a superficial manner the entire field. Apparently this has the approval of some of the deans. But other teachers and deans believe that it is far better to cover more thoroughly only part of the field. In many cases the course covers only mechanics, heat, and electricity and magnetism. There are two different reasons favoring the choice of these three topics. In the first place these three topics include more of the important fundamental principles than any other group of three topics do. In the second place, as indicated in letters from the deans, these three topics cover most of the principles of physics that are used in agriculture. Where the course is limited to only a few hours it does not seem best to try to cover the entire field. If a teacher does try to cover the entire field in a short course he will undoubtedly fail to attain one of the most important

purposes of the course, that is, to train students not only to understand but to be able to use the principles of physics. In fact it is doubtful if a student gets in these short superficial courses much more than a knowledge of a few facts.

There is another aspect to this question of whether the course should be general or not. A general course is one where all the important fundamental principles underlying the science are taught. But in teaching these principles it is absolutely necessary to use many specific applications. This has been discussed at greater length in Sections 11, 12, and 15. In choosing these applications it is also necessary to choose examples in which the students are interested. This makes it necessary in a class consisting in part or in whole of agricultural students to use many agricultural applications. But if these special applications are used to train the student in a broad knowledge of the fundamental principles, the course would still be general in the sense defined here. Hence it is possible for a course to be general and yet have many of the applications drawn from a special field. It does not necessarily destroy the generality of a course to use large numbers of illustrations from a special field. In fact, physics teachers continually draw on the engineering field for illustrations.

It is the opinion of the Committee that the course in physics should be made general so far as the purposes and aims of the course are concerned. But in illustrating the fundamental principles use should be made of those illustrations that can be best understood by the student, even though many of them are taken from special fields. It is the further opinion of the Committee that where the time limitations of the course are severe, the teacher should limit the field covered to mechanics, heat, and magnetism and electricity, rather than attempt to cover the entire field superficially.

18. *Topics recommended by agricultural experts.* The Committee made an effort to collect from agricultural experts lists of topics that should be emphasized in the course in physics. It was found that these experts do not all agree. This is to be expected when it is learned that some will make out only a short list while others make out much longer lists. Then too it requires a great deal of time for one not entirely familiar with the contents of our courses to make accurate suggestions.

However the Committee was fortunate in getting a list which a faculty committee of one college had carefully compiled after consulting all the teachers of agriculture in that college. This list which has been slightly modified as a result of suggestions made by other agricultural authorities is reproduced here. None of these topics has been suggested by a physicist. It is obvious that this list does not take account of the necessity of teaching other topics which are prerequisite to teaching those which are listed.

A knowledge of those topics marked with a star * were regarded by this faculty committee as necessary in the case of all students.

Mechanics. Fundamental units, speed, acceleration, force, *structure of matter, *elasticity, *viscosity, *diffusion, *solution, *capillarity, *surface tension, *gas pressure, *Boyle's law, *specific gravity, *bouyancy, *atmospheric pressure, barometric pressure, *pressure in liquids, suspensions, emulsions, osmosis, *definition of work, *potential and kinetic energy, change of form of energy, availability of energy, conservation of energy.

Heat. *Thermometry, *expansion and condensation of solids, liquids and gases, *absolute temperature, quantity of heat, *specific heat, *calorimetry, *transmission, *radiation, *absorption, *change of state, *fusion, under-cooling, *vaporization, equilibrium of vapor and liquid, *sublimation, *nature of heat, heat of solution, flash point, mechanical equivalent of heat, dewpoint, humidity, frost, heat-engines.

Electricity and Magnetism. Electrostatics, electromagnetism, heating and chemical effects of currents, electrical measurements, difference of potential, electromotive force, electrolytic dissociation, conductivity of electrolytes, electrolytic solution pressure.

Light. Nature of light, refraction, spectrum, absorption and emission lines, optical instruments, polarization.

19. *Systems of units.* The committee believes that the choice of the systems of units to be used and the method of using them, especially in mechanics, should receive greater attention. It is very easy for the student to become confused either because he is using too many different systems or because he is permitted to use wrong units. For example there are several different British systems which when mixed or used simultaneously cause confusion; sometimes the teacher uses a different system from that used in the textbook. Then sometimes the student is confused between the concepts of mass and weight because he uses the *gram* or the *pound* as a unit of both. He does not learn that in the C. G. S. Absolute system the *gram* is a unit of *mass* and not of *weight.* This is discussed much more fully in Report Number 3 of the Educational Committee of the American Physical Society. In conformity with the recommendations of that report the Committee thinks that it is not necessary to teach agricultural students more than two systems of units, the C. G. S. Absolute system and the British Engineering system which is called the "A" system in Report Number 3.

20. *Laboratory Experiments.* The Committee regrets that it has not had the time to make a more detailed study of laboratory work. However such a study should perhaps be much broader than the present investigation. It could well receive special attention of the Educational Committee. Certainly there are many criticisms directed at the great waste of time and effort in our laboratories. Some able students complain because it takes them only about fifteen minutes to understand the details of an experiment, and as they then know exactly how the measurements will turn out, the rest of the period is wasted. It is probable that we do not always place the emphasis in the laboratory on the most important phases.

Teachers were asked by the Committee if they gave experiments which were specially designed for agricultural students. In a few cases teachers reported that special experiments were used. The lists of laboratory experiments which were furnished the Committee show that the usual method was to select common laboratory experiments which illustrate principles that should be stressed with agricultural students. Some experiments were modified to make them more suitable. The following experiments are ones not commonly found in our laboratory manuals.

Specific gravity of soils.
Comparison of porosities and determination of specific pore space.

Specific gravity of alkali solution.
Grade draft, double tree.
Specific heat of soils.

The lists show that it is entirely possible to pick a list of common experiments which are not only suitable for agricultural students but are suitable for the general student. They are however not as difficult or as thorough experiments as most teachers would prefer to give to engineering students.

No case was found where agricultural machinery or special apparatus was used (except the testing of home appliances).

VII. List of Agricultural Applications of Physics

21. There is a great number of suitable agricultural illustrations which can be used effectively to make the meaning of the physical principles clear for students interested in agriculture. Such illustrations have a real advantage over other illustrations because they are already more or less familiar to the student and in many cases the student has first-hand information with respect to the phenomenon and may be assumed to be interested in finding an explanation. By calling the student's attention to such illustrations he would be encouraged to carry his knowledge of physics into his daily work, be stimulated to analyze his physical environment and come to regard physics as an integral part of his agricultural training.

The use of agricultural illustrations in a course in physics presents a number of serious problems which can be successfully handled only by a wise and balanced judgment. In the first place the amount of time available for a course in physics is ordinarily so limited that little opportunity is afforded for the introduction of additional topics, however important they may be for the later work of the student. There is also great danger that too much attention may be given to the agricultural illustrations and too little to the basic physical principles. The work then degenerates into a kind of trade-school course on agricultural processes and appliances. In such an event the student is left without that basic training for which a well-balanced program should call.

In the following paragraphs there is presented a representative list of physical facts which are of importance in the daily life of anyone living on a modern farm. This list is only intended to be suggestive and does not pretend to be complete.

Linear and Angular Velocities and Accelerations. Acceleration of empty and loaded trucks. Angular velocities of pulleys, gear wheels, etc. Regulation of feed in machines like grain drills. (Change in linear speed along a radius. Also used in some "friction-driven" machines).

Momentum. Differences observed in driving empty and loaded cars. Collisions of rapidly moving bodies. Forces exerted at impact by hammers or pile drivers.

Power Work and Energy. Measurement of work done by farm machinery or farm animals. Power, or rate of doing work, by engines or motors. Transformation of kinetic into potential energy as in the pumping of water by a wind mill or in forcing water in form of a spray to the tops of trees.

Composition and Resolution of Forces. Line of draft in a plow and side draft in a plow. The least draft when moving a loaded wagon (a) on a hard, level road (b) over ordinary roads with traces sloping toward the load. Effect on draft of the distribution of the load on the wagon. Forces acting in the case of a short hitch in hauling a load out of a gully. Resolution of the forces operating on a derrick crane, on a stump puller, on a loaded truck on a hillside, on a road machine, on the corner post of a wire fence, on a ladder against a wall, etc. Graphical solution of forces exerted by trusses in the roofs of buildings or bridges.

Moment of Force, or Torque. The relations between the different parts of eveners to give correct load for each horse. Removing heavy rocks by applying a chain in such a way as to introduce a lever arm. The choice between large and small wagon wheels. The transmission gears of an automobile enable the operator to change the moment of force on the rear axle. The torque necessary to drive pulleys of different radii.

Inertia. The effort to start and stop heavy loads. The flow of water in a hydraulic ram. Sudden closing of a water faucet may injure part of the plumbing system. Danger in jumping from a rapidly moving vehicle.

Simple Machines. Wheelbarrows, levers, wagon brakes, combination of levers as in the wagon scale, transmission gears of a motor car. Foot brake in an automobile. Combinations of pulleys. Wheel and axle, windlass, and stump puller. Inclined plane as seen in the rock crusher, hay loader, and wedge. Principle of the screw as found in the jack-screw. Mechanical action of muscles. Judging draft horses on the basis of mechanical principles.

Centrifugal Force. The cream separator, Babcock milk tester, and governor of a steam engine. Separation of honey from the comb. Skidding of cars.

Friction and Viscosity. Sliding friction in case of all surfaces sliding over each other. Rolling friction as in the case of wheels on roads, ball and roller bearings, etc. A truck on a slippery road may exert a greater towing force when loaded. Friction drives for machinery. Transmission of power by belts. Action of lubricants on machinery. Long and short bearings contrasted. Wide and narrow brake bands contrasted. Effect of viscosity on gravity creaming. Effect of viscosity on movement of soil water.

Elasticity and Strength of Materials. Springs on automobiles, "shock absorbers" lengthen the springs. Breaking strength of wires. Stiffness of ordinary beams and I-beams.

Diffusion of Liquids and Gases. Diffusion of air in soils in the process of soil ventilation. Diffusion of gases and their absorption by milks and foliage. Diffusion of gases through membranes in the growth of plants. Diffusion of water vapor in some kinds of soils. Osmosis in plant and animal life. Osmotic pressure in cooking and canning.

Surface Tension and Capillarity. Spring plowing as a means of preventing excessive rise of water. The rapid wearing away of heated bearings. The effect of salts in solution on surface tension and on the capillary movement of such solutions in soils. The rise of water in soils by capillary action. The making of water-proof cloth.

Pascal's Principle. Hydraulic brakes on automobiles. Liquids in communicating tubes as in a water gauge. The hydraulic elevator, ram, press, and crane. Water wheels, pressure on dams and flood gates. Types of water-supply systems. Work done in pumping water.

Archimedes' Principle. Specific Gravity. Determination of the specific gravity of different kinds of soils. Pore space computed from the specific gravity and weight per unit volume. The float valve and the automatic control of a water supply. Bouyancy and stability of floating bodies such as rafts and boats. Hydrometers and lactometers as used in testing batteries and milks.

Pressure of Gases. The barometer and the pressure of the air in meterological work. Movement of the air in soils when the barometer changes. Construction and working principles of the siphon used in the septic tank. Fire bellows, sprayer, force pump, suction pump, compressed-air lift, etc. Air-pressure tank for water system.

Thermometers. Centigrade and Fahrenheit therometers. Maximum and minimum thermometers. Clinical therometers. Resistance thermometers in measuring soil temperatures at different distances from the surface. Thermo-couples for measuring temperature of soil, temperature in silo, or temperature of the hay in a haymow.

Measurement of Heat. Specific heats and thermal capacities of soils and other materials on the farm. Heats of combustion of fuels, solids liquids and gases.

Expansion of Heat. Expansion of solids as wires in fences, tires on wagon wheels, etc. Expansion of liquids as water in a hot-water heating system. Expansion of gases in cooking, heating and ventilating. Rocks are aggregate of matter having different coefficients of expansion. Temperature changes cause disintegration. Differential expansion due to unequal changes in temperature also causes disintegration. Disintegration of rocks is important in soil building. Expansion of air by changes in its temperature assists in soil aeration.

Expansion on Freezing. Effect of freezing on the formation of soil. Late fall plowing an aid to mulch formation. Effect of freezing on clover and other deep rooted plants. Roots of wheat exposed by freezing. Expansion on freezing raises stakes and stones out of the ground.

Freezing Point and Heat of Fusion. The action of a refrigerator. The manufacture of ice. Freezing mixtures and their relation to the manufacture of ice cream. Depression of the freezing point is commonly used in agricultural laboratories to measure the concentration of solutions.

Vaporization of Liquids. Effect of evaporation on the cooling of soils and on the temperature of plants. Heating effect when the soil condenses water vapor from the air. The iceless refrigerator and other cases of cooling by evaporation. Effect of pressure on the boiling point as in the pressure cooker and in vacuum pans. The boiling of liquids under reduced pressure as used in the electric refrigerator. Adiabatic expansion and compression in the production of clouds, rain, dry winds. Warming of air by condensation of water vapor increases the upward rush of air in a thunder storm. Distillation and purification of water, household stills. Saturated and non-saturated vapors, clouds, dew, fogs, humidity, etc. Pressure of saturated vapor depends on curvature of water surface, when soil pores are fine, "capillary" water does not evaporate so rapidly. Water tends to evaporate in warmer parts of soil and condense in cooler parts. Relative humidity affects transpiration of plants and evaporation from soils.

Convection of Heat. Draft of a stove, hot-water furnace, hot-water tank, and radiator of a gasoline engine. Hot-air heating, ventilation of houses and stock barns. Fruits and plants on high ground are in less danger of freezing than those on low lands. Causes of winds, cyclones, tornadoes, thunder storms, etc.

Conduction of Heat. Thermal conductivity of soils. Loose soils are poor conductors of heat. Rolling the soil after seeding makes the soil a better conductor of heat. Hollow brick walls are poor conductors of heat. Covering pipes with asbestos to prevent loss of heat. Construction of refrigerators. Construction of ice houses. Winter storage of vegetables. Poor conductivity of snow, straw, and mulches. Fireless cookers, concrete floors, etc.

Radiation of Heat. Absorption of radiation by soils of different colors. For early gardens a soil that warms quickly is desirable. Absorption of radiation by the atmosphere. Influence of slope on the temperature of soils. Action of a cold frame. Bright radiators of a heating system radiate little heat. The thermos bottle. Milk is hauled in large vacuum-jacketed tanks. The temperature of soils at different times of day and night is related to radiating and absorbing power of the soils. Twigs of fruit trees are good absorbers of radiation, winter killing of fruit is due to premature growth. Large range of temperature of bark on south side of trees causes winter growth and subsequent injury to trees.

Heat and Work. Transformation of heat into work by steam and gas engines. Measurement of horse power and efficiency of engine motors. Operation of refrigerating machines (two types).

Static Electricity. Lightning and the explanation of lightning rods. Danger in handling gasoline (gasoline or clothes washed in gasoline easily charged).

Chemical Effect of an Electric Current. Methods of electroplating. Action of dry cells and storage cells. A large portion of soil nutrients are in an ionized condition. (Water must be present in soil for ions to diffuse to plant roots.)

Ohm's Law and the Fall of Potential in a Conductor. Relation between current and electromotive force in a farm-lighting plant. Loss of potential in a dynamo or in the lead wires from the dynamo. Electrical currents and electromotive forces for different household electrical appliances. Charging storage batteries with a dynamo. Charging storage batteries from alternating-current circuit.

Heating Effect of Electric Currents. Energy spent in heating by electricity as in an electric iron, electric stove, electric toaster, etc. Operation of electric fuses. Incubators heated by electric currents. Action of a thermostat of an incubator. Use of electric heating in blasting.

Magnetic Effects of an Electric Current. Electromagnets, magnetos, motors, dynamos. Electrical measuring instruments, voltmeters, ammeters, kilowatt-hour meter. Magnetic brakes, magnetic separators. Farm-lighting plants.

Induced Currents. Make and break induction coils. Generators. Telephone transmitters. Wireless telephones, including audion tubes.

Sound. Absorption of sound by different materials. Reflection of sound in the interiors of buildings. Transmission of sounds by different types of substances.

Light. Intensity of light, units of measurement of light, distribution of light, glare, etc. Nature of modern illuminants, principles of light control. Production of color. Importance of exposing animals to ultra violet light. Effect of light on the production of eggs in poultry. Sterlization of water by ultra violet light. Orientation of different plants and animals with respect to the direction ot the light. Effect of lights of different color on the rate of plant growth.